Appendix F Financial Calculations

This section presents all the major financial parameters of ReEDS. It begins with general economic parameters that are used in the ReEDS economic calculations.

F.1 General Economic Parameters

Fundamental parameters

d, the real discount rate.

E, the evaluation period or investment lifetime, in years.

CRF, the capital recovery factor, is computed from d and E and represents the fraction of the capital cost of an investment that must be returned each year to earn a rate of return equal to d, ignoring income taxes and financing.

$$CRF = \left(\sum_{t=1}^{E} (1+d)^t \right)^{-1} = \frac{d}{1-(1+d)^{-E}}$$

F.2 Financial Parameters Specific to Wind

This subsection includes many of the cost parameters that are calculated for wind.

CW_c is the present value of the revenue required to pay for the capital cost of one MW of wind capacity ($/MW) including interest during construction, finance, and taxes.

$$CW_c = WCC_c \cdot \frac{IDC}{1-TR} \cdot \begin{pmatrix} (1-FF) + FF \cdot PVDebt \\ -TR \cdot (1-ITCW/2) \cdot PVDep - ITCW \end{pmatrix}$$

where

WCC_c is the overnight capital cost ($/MW) of a class c wind plant. WCC_c can be either a direct input ($IWLC = 0$) or calculated based on a production learning curve ($IWLC = 1$). If learning-based improvements are allowed, then

$$WCC_c = WCC_c^0 \cdot \begin{pmatrix} (1-costinstfrac)(1-learnpar_{wind})^{\log_2\left(WROW + \frac{WindCap_{T\_delay}}{W_0}\right)} \\ +constinstfrac \cdot (1-learnpar_{wind})^{\log_2\left(\frac{WindCap_{T\_delay}}{W\_UScapyr2000}\right)} \end{pmatrix}$$

where

WCC^0_c is the overnight capital cost ($/MW) of a class *c* wind plant without learning as input for the time period (i.e., includes any R&D driven changes over time, but not learning).

costinstfrac is the fraction of the capital cost associated with installation.

$learnpar_{wind}$ is the learning parameter for wind, the % reduction in the capital cost of wind for each doubling of the installed capacity.

WROW is the wind capacity installed in the rest of the world T_delay periods ago.

T_delay is the time required for learning to impact the market, i.e. the learning delay in periods between installations and cost reductions.

$WindCap_{T\_delay}$ is the total national installed wind capacity T_delay periods ago.

*W_UScapyr*2000 is the total national capacity in the year 2000.

W_o is the total world wind capacity in the year 2000.

IDC is a multiplier to capture after-tax value of interest during construction.

$$IDC = \sum_{t=1}^{CP} CONSF_t \cdot \left(1 + (1 - TR) \cdot ((1 + i_c)^{CP-t} - 1)\right)$$

where

$CONSF_t$ is the fraction of the capital cost incurred in year t of construction.

i_c is the construction loan nominal interest rate.

CP is the construction period.

TR is the combined federal and state marginal income tax rate.

FF is the fraction of the plant capital cost financed. It can be input or calculated as shown below (see DSCR discussion) to ensure that the required debt service coverage ratio (DSCR) is met.

ITCW = investment tax credit for wind.

PVDebt is the after-tax present value of debt payments. [13]

$$\begin{aligned} PVDebt &= \sum_{t=1}^{L} \frac{P_t + (1 - TR)I_t}{(1 + d_n)^t} \\ &= CRF_{i,L} \cdot (1 - TR) \cdot PVA_{d_n,L} + TR \cdot \left(\frac{CRF_{i,L} - i}{1 + i}\right) \cdot PVA_{d_n,L} \end{aligned}$$

where

[13] Closed-form expression for the after-tax present value of the loan payments. Define Pt as the principal payment in year t, and i as the nominal interest rate, then the cost of the loan payments over the life L of the loan is:

P_t is the principal portion of the finance payment made after the loan has been in place t years.

I_t is the interest portion of the finance payment made after the loan has been in place t years.

i = nominal interest rate for debt.

L = financing period.

$PVA_{d_n,L}$ is the present value of annual \$1 payments for L years.

$PVDep$ is the present value of depreciation

$$PVDep = \sum_{t=1}^{DP} \frac{Depf_t}{(1+d_n)^t}$$

where

$Depf_t$ = depreciation fraction in year t

DP = depreciation period

$CWOM_c$ is the present value of E years of operating costs including property taxes, insurance, and production tax credit (\$/MW).

$$CWOM_c = WOMF_c \cdot PVA_{d,E} + 8760 \cdot CF_c \cdot (WOMV_c \cdot PVA_{d,E} - \frac{WPTC}{1-TR} \cdot PVA_{d,PTCP})$$

where[14]

$WOMF_c$ is the fixed annual O&M cost of class c wind (\$/MW-yr)

$WOMV_c$ is the variable O&M cost of class c wind (\$/MWh)

$WPTC$ is the production tax credit (\$/MWh)

$PTCP$ is the period over which the production tax credit is received (years)

CG_g is the increase in turbine price over cost due to rapid growth in wind deployment. (\$/MW)

$$\begin{aligned}
CG_1 &= 0.01\\
CG_2 &= (1 - Cost_Inst_Frac) \cdot CW_6 \cdot GP \cdot (BP_2 - BP_1)/2\\
CG_3 &= (1 - Cost_Inst_Frac) \cdot CW_6 \cdot GP \cdot (BP_2 - BP_1 + (BP_3 - BP_2)/2)\\
CG_4 &= (1 - Cost_Inst_Frac) \cdot CW_6 \cdot GP \cdot (BP_3 - BP_1 + (BP_4 - BP_3)/2)\\
CG_5 &= (1 - Cost_Inst_Frac) \cdot CW_6 \cdot GP \cdot (BP_4 - BP_1 + (BP_5 - BP_4)/2)\\
CG_6 &= (1 - Cost_Inst_Frac) \cdot CW_6 \cdot GP \cdot (BP_5 - BP_1)
\end{aligned}$$

where

CW_6 is the cost of a class 6 wind machine

GP is the growth penalty for each percent growth above the breakpoint

BP_k are breakpoints that discretize the growth price penalty: $(1 < BP_1 < BP_2 < BP_3 < BP_4 < BP_5 < BP_6)$

[14] The use of a real discount rate in all the O&M calculations presumes that the O&M costs increase with inflation, i.e. that the real O&M cost is unchanging.

$CGinst_{ginst}$ is the increase in wind installation price over cost in growth bin ginst, due to rapid growth in wind deployment. ($/MW)

$$
\begin{aligned}
CGinst_1 &= 0.01 \\
CGinst_2 &= Cost\_Inst\_Frac \cdot CW_6 \cdot GPinst \cdot (BP_2 - BP_1)/2 \\
CGinst_3 &= Cost\_Inst\_Frac \cdot CW_6 \cdot GPinst \cdot (BP_2 - BP_1 + (BP_3 - BP_2)/2) \\
CGinst_4 &= Cost\_Inst\_Frac \cdot CW_6 \cdot GPinst \cdot (BP_3 - BP_1 + (BP_4 - BP_3)/2) \\
CGinst_5 &= Cost\_Inst\_Frac \cdot CW_6 \cdot GPinst \cdot (BP_4 - BP_1 + (BP_5 - BP_4)/2) \\
CGinst_6 &= Cost\_Inst\_Frac \cdot CW_6 \cdot GPinst \cdot (BP_5 - BP_1)
\end{aligned}
$$

where

GPinst is the growth penalty for each percent growth above the breakpoint

F.3 Setting the Finanace Fraction in ReEDS

The fraction of the capital cost of a wind farm that is financed can be input or endogenously estimated based on debt-service requirements. If calculated endogenously, the maximum fraction that can be financed is used. The fraction that can be financed is restricted by the Debt Service Coverage Ratio (DSCR). DSCR is the ratio of net pre-tax revenue to the debt payment (Debtpayment). ReEDS assumes the net pre-tax revenue is equal to the revenue required to recover capital cost plus profit and tax benefits (e.g., production tax credit).

$$DSCR = \frac{CRF_{d_n,E}}{Debtpayment} \cdot \left(CW_c + \frac{WPTC \cdot 8760 \cdot CF_c}{(1 - TR) \cdot PVA_{d,PTCP}}\right)$$

where

$$Debtpayment = FF \cdot WCC \cdot IDC \cdot CRF_{i,L}$$

Solving the DSCR equation for the finance fraction (which is embedded in CW_c, above) yields:

$$FF = CRF_{d,E} \cdot \frac{\frac{WPTC \cdot 8760 \cdot CF_c}{1 - TR} \cdot PVA_{d,PTCP} + \frac{WCC \cdot IDC}{1 - TR} \cdot \left(1 - TR \cdot (1 - \frac{ITCW}{2}) \cdot PVDep - ITCW\right)}{WCC \cdot IDC \cdot \left(DSCR \cdot CRF_{i,L} + \frac{(1 - PVDebt) \cdot CRF_{d,E}}{1 - TR}\right)}$$

F.4 Financial Parameters Specific to Conventional Technologies

This section includes many of the cost parameters that are calculated in ReEDS for conventional technologies. Inasmuch as some of these are substantively the same as those calculated for wind, the reader will be referred to the above wind parameter subsection.

$CCONV_q$ is the present value of the revenue required to pay for the capital cost of one MW of capacity of generating technology q ($/MW) including interest during construction, finance, and taxes. It is calculated in a manner analogous to that for wind.

$$
\begin{aligned}
CCONV_q = CCC_c \cdot \frac{CRF_{d,E}}{CRF_{d,L_q}} \cdot \frac{IDC}{1 - TR} \\
\cdot ((1 - FF) + FF \cdot PVDebt - TR \cdot (1 - ITC_q/2) \cdot PVDep - ITC_q)
\end{aligned}
$$

where

CCC_c is the overnight capital cost (\$/MW) of the generation plant. CCC_c can be either a direct input (ILC = 0) or calculated based on a production learning curve (ILC = 1). If learning-based improvements are allowed, then

$$CCC_c = CCC_0 \cdot (1 - costinstfrac)(1 - learnpar_{wind})^{\log_2\left(\frac{CONVOLDdelay_q}{USCapyear2000_q}\right)}$$

where

> CCC_o is the overnight capital cost (\$/MW) of generating technology without learning as input for the time period (i.e., includes any R&D driven changes over time, but not learning).
>
> $CONVOLDdelay_q$ is the learning delay between installations and cost reductions.
>
> $learndelay$ is the learning delay between installations and cost reductions.
>
> $learnpar_q$ is the learning parameter for generation technology q, the % reduction in the capital cost for each doubling of the installed capacity.
>
> $UScapyr2000_q$ is the total national capacity of generation technology q in the year 2000.
>
> L_q is the economic lifetime of technology q (years).
>
> FF is the finance fraction which must be input for conventional technologies (unlike the endogenous calculation option for wind described above).
>
> See the calculation of CW_c for the definition of the other inputs for CCC_q

$CCONVV_{n,q}$ is the present value of the variable cost of operating technology q in balancing authority n for E years.

$$CCONVV_{n,q} = CVarOM_q \cdot PVA_{d,E} + Fprice_{q,n} \cdot cheatrate_q \cdot PVA(n,q)_{d,E,e}$$

where

> $CvarOM_q$ is the variable O&M cost for technology q (\$/MWh).
>
> $Fprice_{q,n}$ is the cost of the input fuel (\$/MMBtu).
>
> $cheatrate_q$ is the heat rate for technology q.

$CCONVF_q$ is the present value of the fixed costs of operating technology q for E years (\$/MW).

$$CCONVF_q = COMF_q \cdot PVA_{d,E}$$

where

> $COMF_q$ is the annual fixed O&M cost for plant type q (\$/MW-yr).

$CSRV_{n,q}$ is the present value of the variable cost of spinning reserve provided for E years in balancing authority n (\$/MWh). The cost represents the cost of operating the plant at part-load. A linear program can not ordinarily capture part-load efficiency, because it is highly nonlinear with the level of operation. ReEDS assumes that if spinning reserve is provided, the maximum amount is provided in the time-slice, the plant is operating at $MinSR_q \cdot CONV_{n,q}$. Thus, the cost of spinning reserve can be estimated by solving the following for $CSRV_{n,q}$:

$$CCONVV_{n,q} \cdot \frac{MinSR_q \cdot CONV_{n,q}}{PLEffFactor_q} = CCONVV_{n,q} \cdot MinSR_q \cdot CONV_{n,q} + (1 - MinSR_q) \cdot CONV_{n,q} \cdot CSRV_{n,q}$$

or

$$CSRV_{n,q} = \frac{MinSR_q}{1 - MinSR_q} \cdot CCONVV_{q,n} \cdot \left(\frac{1}{PLEffFactor_q} - 1\right)$$

F.5 Transmission Cost Parameters

$CCT_{n,p}$ is the present value of transmitting 1 MWh of power for each of E years between balancing authorities n and p (\$/MWh).

$$CCT_{n,p} = (Dis_{n,p} \cdot TOCOST + POSTSTWCOST \cdot PostStamp_{n,p}) \cdot PVA_{d_n,E}$$

where

$Dis_{n,p}$ is the distance in miles between the center of balancing authorities n and p.

$TOCOST$ is the cost per mile for using existing transmission lines (\$/MWh-mile).

$POSTSTWCOST$ is the cost of using transmission that crosses a balancing authority (\$/MWh).

$PostStamp_{n,p}$ is the number of balancing authorities that must be crossed to move from n to p. If p is adjacent to n, getting to p is considered to be crossing one balancing authority.

$TN\_CG_{tn\_g}$ is the difference between the price and cost of transmission in transmission growth bin tn_g (\$/MW-mile).

$$\begin{aligned}
TN_CG_1 &= 0.01 \\
TN_CG_2 &= TNCost \cdot TNGP \cdot (TNBP_2 - TNBP_1))/2 \\
TN_CG_3 &= TNCost \cdot TNGP \cdot (TNBP_2 - TNBP_1) + (TNBP_3) - TNBP_2))/2) \\
TN_CG_4 &= TNCost \cdot TNGP \cdot (TNBP_3 - TNBP_1) + (TNBP_4) - TNBP_3))/2) \\
TN_CG_5 &= TNCost \cdot TNGP \cdot (TNBP_4 - TNBP_1) + (TNBP_5) - TNBP_4))/2) \\
TN_CG_6 &= TNCost \cdot TNGP \cdot (TNBP_5 - TNBP_1))
\end{aligned}$$

where

$TNCost$ is the cost per mile of building new transmission lines (\$/MW-mile).

$TNGP$ is the percent increase in the cost of transmission for each percent growth over the base amount.

$TNBP_k$ are breakpoints that discretize the growth price penalty: $(1 < TNBP_1 < TNBP_2 < TNBP_3 < TNBP_4 < TNBP5 < TNBP_6)$